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The Application of Information Theory to a Single Visual Search Task

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THE APPLICATION OF INFORMATION THEORY

TO A SINGLE VISUAL SEARCH TASK

(TITLE)

BY

Charles F. Gidcumb

THESIS

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Historical Background

Since the time of the first psyohological research, psychologists have attempted to unlock the secrets involved in the processes enabling man to function in his environment. However, psychology has been hampered by a paucity of soi-entifio tools to provide quantitative measurement. Just as the telescope helped astronomy and the microscope helped the biologioal sciences, information theory and its developments have helped the science of psychology. Out of information theory was developed a method of quantifying many of the phenomena psychology investigates, which previously had only been discussed in qualitative terms (Alluisi, 1960).

Originally, information theory was developed for use with the complex problems of teleoommunications. Called communication theory its principles were soon found to be generalizable to other areas of research and application.

Shannon is credited with the formalizing of the theory in a paper published in 1948 which dealt with the mathematical theory of communication. Later, in 1949, Shannon's paper and a less mathematical paper by Weaver explaining

Shannon's paper were published together (Shannon and Weaver, 1949). That same year Miller and Frick (1949) introduced the concepts of communication theory to the psychological literature. A special conference on the use of information theory in psychology was held at Harvard University in 1951 (Garner, 1958). Since then much has been written and much research has been done using the concepts of information theory to meet the needs of a growing psychology.

Attneave (1950) defines information as "that which removes or reduces uncertainty." Uncertainty can be described in terms of the possible number of alternatives from which a choice is to be made. If a person has 20 alternatives, the uncertainty of which alternative he will choose is greater than when only 10 alternatives are available. When an observer reduces the number of alternatives contained is a particular set of alternatives the amount of uncertainty is also reduced. By Attneave's definition information is required to reduce uncertainty, therefore, the observer in reducing the number of alternatives is said to have gained information. In other words the greater the number of alternatives present, the greater the uncertainty, and the greater the amount of information. A reduction in the number of alternative requires a gain in information.

What is needed now is a means of measuring how much information is gained or conversely how much uncertainty is eliminated. Counting the number of possible alternatives is a very simple and direct method of determining the amount of uncertainty present. Arriving at the amount of information gained would then be the simple task of determining how many possible alternatives are eliminated. Therefore, the number of alternatives eliminated would be the number of units of information gained. This form of measurement, though, does not allow equal units of information to be obtained with equal reduction of uncertainty. The reduction of 100 to 99 would not reduce the uncertainty as greatly as the reduction of ten alternatives to nine, even though they both were reduced by one alternative.

The use of ratios will solve the problem. The reduction of 100 alternatives to 50 would be as great a reduction of uncertainty as reducing ten to five alternatives. Whenever the number of alternatives is reduced by one half, then one unit of information could be said to have been gained. This is just what the theorists did, giving the unit of information the name "bit" which is short for binary digit. The following problem is given as an illustration of the use of the bit as a unit of information measurement. Sixteen boxes are placed in front of a subject, one of which contains a dollar bill. The subject is told to guess which box the dollar bill is in. He is also told he may ask questions to determine which box he will choose, but he must ask as few questions as possible. The most efficient question would eliminate half of the possiblities, that is, gain one bit of information. The questions might take the following form:

1. Is it in one of the first eight boxes? (No)
2. Is it in the first four of the remaining eight boxes? (Yes)
3. Is it in the first two of those four boxes? (No)
4. Is it in the first of the other two boxes? (No)

Even though the last answer was "No," the subject now knows which box contains the dollar bill, the twelfth box. So he found the money with only four questions. Since each question reduced the number of possibilities by one half, each obtained one bit of information for the subject. Therefore, for 16 alternatives, four questions each resulting in a gain of one bit of information will reduce the uncertainty to one and effectively remove it.

This process of halving was expressed mathematically by Shannon (Shannon and Weaver, 1949). The following sequence of steps demonstrates how to determine the number of times a set of alternatives can be halved or how many bits of information are obtainable from a set of alternatives. The number of times the possible alternatives can be halved is expressed in the following equation:

$$k = 2^n \qquad \text{Equation 1}$$

where k is equal to the number of alternatives and n is equal to the number of times the alternatives can be halved. In other words n is equal to the number of bits of information contained in k alternatives. Since the number of bits contained is the desired measure, that term of the equation must be isolated. This is done in the following equation:

$$\log_2 k = n \qquad \text{Equation 2}$$

Substituting the values from the example described above into Equations 1 and 2, the following is obtained:

$$16 = 2^4 \qquad \text{Equation 3}$$

$$\log_2 16 = 4 \qquad \text{Equation 4}$$

Therefore, Equation 2 can be used as the formula to find the number of bits of information contained in a set of alternatives. With the use of Equation 2 the desired method of measuring the amount of information acquired is obtained.

While the methods of information theory provide a measure of the amount of information little can be said for the content of the information. The meaning, purpose, usefulness, value or truthfulness of the information can not be measured with this method, only the amount of knowledge acquired which was not known before is measured (Shannon and Weaver, 1949). Many of the claims concerning the importance of information theory have been clouded by the failure to adhere to the strict definition of information used in the theory. This failure has led many critics to discount the true value of information theory as a tool for quantitative measures in psychology (Miller, 1953).

In establishing his mathematical theory Shannon described a complex communication model (Shannon and Weaver, 1949). For their use psychologists simplify the communication model to only four parts; the source, the channel, the destination, and noise. The source, sometimes called the input, is the environmental stimulus. The channel is man himself. The destination, usually referred to as the output, is the response exhibited. Noise constitutes any distortion introduced by the channel between stimulus and response, or input and output. Therefore, a psychologist observing a difference between the inout and the output can assume that the distortion occurred within the channel or the subject. Examining the noise and then analyzing it according to the information model, the psychologist is led to a greater understanding of some of the processes that allow man to function in his environment.

Review of Literature

One of the applications of the psychological adaption of the communication model is to measure the rate of information handling capacity of man. The time needed to process a given amount of information would provide the required measure of rate. The classic reaction time experiment would seem to meet the experimental requirements for determining such a handling rate. By controlling the amount of information contained in the stimulus eliciting the response, the information contained in the stimulus can then be divided by the reaction time and result in a measure of information units per unit of time.

The data of the classical reaction time experiment produces a very crude measurement of the information handling rate though. This is the result of a confounding of the processing time with the time needed to prepare and execute the physical response. Neisser (1963) devised a type of reaction experiment which effectively eliminated the preparation and execution time from the reaction time leaving an almost pure measure of processing time. Neisser's design used visual scanning of a list of items. Each item consisted of a string of six letters with the items listed in a column of 50 items. The task given to the subject was to find a specific letter or target which was either the only such letter present or the only letter absent. The subject, in order to perform the task, must examine each item but make no response until the target is found. The rate at which the subject scans the list would then be a measure of the time used to examine the items that elicit no response.

Neisser (1963) conducted several experiments to validate and determine the breadth and flexibility of the technique. He found the method to be reliable and his results indicated that several processes of recognition could function simultaneously and that identification of a missing letter was more difficult than identification of a letter which is present.

In another study (Neisser, Novick, and Lazar, 1963) subjects were given the same type of task but were required to search for 1, 5, or 10 target letters or numbers. A list consisted of 50 items in a single column with each item consisting of six letters and/or numbers. Neisser, et. al., found no difference in search times between the 1, 5, or the 10 target conditions after 12 days of practice. These results corroborated those found in the previous study (Neisser, 1963) which indicated that several reoognition processes could function simultaneously. As a result, these two studies establish two main points about search tasks. One, search tasks provide a reliable measure of the information processing or handling rate of man, and second, that more than one recognition process can function simultaneously.

Hyman (1953) used a six by six matrix of 36 lights to determine the effect of differing amounts of information or information load on reaction time. In his experiment the subjects associated a distinctive name for one of eight lights used as the stimulus. The eight lights consisted of the four lights making up the four corners of the outer square of lights and the four corners of the next inner square of lights. This was done to minimize the confusion of one light with another on the matrix by the subject. For each trial the subject's reaction time was measured from the onset of one stimulus light until he responded with the name associated with that light. Hyman varied the amount of information the subject had to process by varying the number of lights from which the stimulus might appear. Hence if a subject was told the stimulus light would be one of two lights the subject had to process one bit of information, but if the stimulus light would be one of eight lights the subject then had to process three bits of information. By increasing the number of lights the amount of information to be processed also increased, since there was greater uncertainty as to which light would be the stimulus light. Hyman found the reaction times increased as a linear function of the information load. Similar results were found by Archer (1954), Solley and Synder (1958), Thomas and Solley (1963), Oostlander and de Swart (1966), and Olshavsky and Gregg (1970). It would seem that when a greater amount of information is to be handled, a greater amount of time is needed to process it.

Gregg (1954) tested subjects on the effect of unneeded or irrelevant information on reaction time. He used two levels of spatial position, size, or brightness as the dimensions from which the subject must determine what response to make. Each subject was instructed to find a target based only on information pertaining to one of the dimensions used. Since the subject chose from only two possibilities, each choice gave the subject one bit of information. By adding a second dimension (e.g., such as position to brightness) the subject was given an extra bit of information which was irrelevant to his task. Adding the size dimension to the other two would increase the amount of irrelevant information to two bits. He found increases in the amount of irrelevant information increased the reaction times of his subjects. Archer, Bourne, and Brown (1955) also found that increasing the amount of irrelevant information resulted in an increase in reaction time. Apparently, irrelevant information even though not part of the required task, requires some processing time.

Irrelevant information does not always interfere with performance, however, Archer (1954) used the following example to illustrate this point. The traffic sign bearing the word "Stop" contains more information than is needed for the message to be understood. The shape and color of the sign add nothing to information obtained from the word "Stop." However, the information conveyed by the color and shape is the same as the word "Stop," and these are therefore, considered redundant pieces of information. Then a redundant piece of information is considered to be irrelevant information which duplicates an essential piece of information.

Rappaport (1957) found that in situations where no noise was present in the stimulus itself, the amount of redundancy produced no effect on performance of a visual recognition task. However, when noise was present in the stimulus, redundancy was found to decrease the recognition time. This indicates that redundancy can aid performance even though the information is irrelevant to the performance of the task.

Another approach concerning redundancy was taken by Green and Anderson (1956). They used redundancy in the form of a color code to reduce the search time of a visual search task. The subject was to locate a two digit target number in a matrix of six columns and ten rows. One group of subjects received the target number and no code while the other group received a color code along with the target number. The coding consisted of red or green coded numbers (one of which was the target) in six code densities. The densities were 10, 20, 30, 40, 50, or 60 numbers of the same color as the target. The target colors were either red and the remaining numbers green or green and the remaining numbers red. All subjects viewed the same matrices and in all cases the color was unnecessary to the subject in order for him to find the target number and therefore, was irrelevant. For the group receiving the code, the color information was redundant since it duplicates the information concerning the target. Subjects receiving the target and color code were found to have shorter search times than subjects receiving the target and no code. Apparently the redundant coding did indeed facilitate shorter search times.

Smith (1962) used a similar search task but investigated the effects of background color used (black and white) and target colors used (red, green, blue, orange, and black/white). He found that the background color and the particular color of the target produced no significant difference in search times. As in the Green and Anderson (1956) study, Smith found subjects given the code performed better, had shorter search times, than subjects not given the code. It would seem that the coding effect on search times is independent of the background color or colors used in the coding forms themselves. Therefore, the colors chosen to form the code are not important as long as the code is redundant.

Eriksen (1952) used a search task to test four dimensions of coding; hue, form, brightness, and size. He varied each of the dimensions along seven levels. The subject's task was to find the target as defined by one level of one dimension or by one level of several dimensions (e.g., one level of hue or one level of both hue and form). The target was embedded in a matrix of seven rows and seven columns of symbols varying along the several dimensions. He found that search times for targets varying by hue alone were significantly shorter than either brightness alone or size alone. Eriksen (1952) also found that a compound of hue and form produced shorter search times than any of the other possible compounds. Eriksen also tested for the possible effects of sex differences, but found none to exist. A second study by Eriksen (1953) using essentially the same technique found that search time decreased when the number of dimensions by which the target was defined were increased. For instance, in a heterogenous field varying along hue and form dimensions, targets defined according to both hue and form were found more quickly than targets defined by either hue alone or form alone. From the work done by Eriksen it seems that the use of hue alone and form alone as coding dimensions would be most effective in reducing search times. The use of a compound of hue and form would seem to reduce the search time even more. In other words, the greater the amount of redundancy with respect to the target the shorter should be the search times. Also, the sex of the subject seems not to be a variable influencing the search times.

Meudell and Whiston (1970) analyzed the data from the Green and Anderson (1956) study according to information theory. While Green and Anderson found significant differences in search times between the group receiving the code and a control condition, Meudell and Whiston (1970) found that subjects in the control condition were processing information at the same rate as the code condition. It seems on the basis of this analysis that subjects engaged in a search task process information at a constant rate regardless of the conditions imposed by the experimenter.

From the literature cited one should be able to make the following assumptions.

1. The use of a visual search task produces an almost pure measure of processing time.
2. The subject can process more than one recognition task at a time.
3. More time is required to process the information in a recognition task involving a large amount of information than one involving a small amount of information.

4. Irrelevant information, while not necessary in the performance of the task, requires processing time and therefore, increases the total processing time.
5. Redundant information seems to reduce processing time.
6. Sex of the subject is not indicated as a factor which influences the search times of the subject.
7. Information processing rates appear to be constant for humans performing visual search tasks.

Statement of Purpose

The purpose of this study was to investigate the effects of redundancy, information loading, and irrelevant information on the information processing rate of humans.

The basic processing rate was determined by a visual search task similar to that of Green and Anderson (1956). Twenty-four number matrices consisting of six columns and ten rows formed the stimulus. Neisser's (1963) study indicates that a visual search task will give a relatively pure measure of the processing rate of the subject.

The effect of redundancy was measured by the use of coding similar to that used in the Green and Anderson (1956) study. In the first of two conditions a group of subjects was given the code of the target before they began searching for the target. For the second, subjects were not given any code before search for the target began. Based on the findings of the Green and Anderson (1956) study, the subjects not receiving the code should have the longest search times.

While Green and Anderson (1956) used color as the code, this study used form, triangles and circles, as the code.

The triangles and circles were used in the same manner as Green and Anderson (1956) used the colors red and green. Since Eriksen (1952) found the greatest facilitation in search time with color, form, and color-form definitions, the results of this study should be comparable to those of Green and Anderson (1956).

The effect of information loading was measured by increasing the density of numbers from which the target must be found. Six levels of information loading were used in a fashion similar to the coding densities of Green and Anderson (1956). Hyman's (1953) data indicated the processing time increased as the amount of information to be processed was increased.

Irrelevant information effects were measured by comparing two conditions. The irrelevant information condition had all 60 positions of the six by ten matrix filled by the coded numbers and the uncoded numbers. Since the subjects in the coding condition needed only to search the coded numbers for the target, the uncoded numbers were irrelevant to the task. For the second condition, the control condition, only the coded numbers were present with the uncoded numbers being left out of the matrix. This resulted in the condition having no irrelevant information present. Comparison of these two conditions allowed the difference in search times between conditions to be attributed to the absence of irrelevant information in the control condition. On the basis of Gregg's (1954) study one would predict irrelevant information to increase the search time since more information is present to be processed.

The data from this study was analyzed in the manner of Meudell and Whiston (1970). As in the Meudell and Whiston (1970) study, the processing rates should be constant across conditions.

The specific hypotheses advanced are:

1. The subjects receiving the code will perform better than the subjects receiving no code.
2. The greater the target density the greater will be the search times of the subjects.
3. The control condition having no irrelevant information should produce the shortest search times of all conditions.
4. The processing rate of all conditions should be the same.

Method

Subjects. The forty subjects employed in this experiment were undergraduate psychology students of both sexes at Eastern Illinois University.

Material. The subjects each viewed 24 displays one at a time. The display images were projected on a white screen by a Kodak Carousel slide projector using Ektachrome slide transparencies. The projected image was 16 inches wide and 24 inches long with numbers 3/4's of an inch wide and 1½ inches long. The subject was seated 10 feet from the screen to view the displays.

The displays consisted of number matrices having six columns and ten rows. The numbers ranged from 12 through 84 with all double digits (e.g., 22, 33, 44, etc.) omitted and all numbers ending in zero (e.g., 20, 30, 40, etc.) omitted. The numbers were randomly assigned with each number appearing only once per matrix.

One half of the displays made up the irrelevant information group. One number on each display was chosen as the target number for that display. The target number was chosen randomly with the stipulation that half of the targets must occur between rows one through five and the other half between rows six through ten. Once the target was chosen, a form to be used as the code for that target was randomly determined. Two geometric forms were used to code the target number which the subject was asked to find. Since the forms were not necessary for the subject to find the target they were redundant information. Along with the target in the coding condition a subject was also given its form which was then identified as the target code. As examples the number 32 might be coded with a triangle or the number 75 might be coded with a circle. After assignment of a code form was completed, one of six densities were randomly assigned until one display of each density was obtained. Density in this case refers to the number of alternatives within which the target may be found. The densities were 10, 20, 30, 40, 50, or 60 numbers of the target code form. An example would be a target code of a circle and the density level of 40. This means that 40 of the 60 numbers were superimposed on circles and the remaining 20 numbers were on triangles. The numbers assigned the code form were randomly chosen with the restriction that half of them be in rows one through five and the other half in rows six through ten. As an example, one matrix might have the number 18 chosen as the target, triangle as the code form, and 10 as the density. This means that eighteen will be superimposed on one of ten triangles and that five numbers in rows one through five will be superimposed on a triangle and five numbers in rows six through ten will be superimposed on a triangle. All the other numbers will be superimposed on a circle. This process of selecting target, code form, and density continued until six matrices of each code form and one of each density were chosen resulting in twelve displays.

An additional twelve displays composed the control group. This group had targets, code forms, and densities assigned as in the irrelevant information group. The difference between groups was the removal of all non-coded numbers from the matrix. The result, for example, might be a matrix with the target number of 31, code form of a triangle and a density of 40. Such a matrix would then have 20 empty places instead of 20 numbers superimposed on a circle as would be the case in the irrelevant information condition (See Appendix A).

In addition to the displays already mentioned a third and fourth set of displays were prepared. These displays were identical to the first two sets except the target chosen was not present on the display. The second set of displays were used to prevent subjects from stopping the timer before actually locating the target and then using the time immediately after to actually locate the target.

<u>Procedure</u>. The experimenter verbally presented each

subject with the target number and depending upon which subject group the subject belonged, the target's code. The subject was then instructed to repeat the target or target and code to prevent any misunderstanding. When the subject had repeated the target correctly, the experimenter depressed a switch causing the projector to cycle. The stop clock began as soon as the next stimulus appeared. Upon locating the target the subject stopped the clock by pressing a hand held push button switch. The subject was then required to indicate the location of the target on the matrix. All subjects were told of the dummy slides and instructed to stop the clock only when they had determined that the target was or was not present. Three practice trials were given, one each of a control, non-control, and dummy display. The actual instructions given the subject are presented in Appendix B.

Results

Appendix C presents the summary of an analysis of variance performed on the data. The analysis indicates no significant difference between the code and non-code groups. The means used to make the plots in Figure 1 of the code by control interaction are found in Appendix D as are the means used for the graphs in the other figures. Examination of the plots in Figure 1 show little difference between the code and non-code groups for the control condition. However, a large difference is observed between the code and non-code groups for the non-control condition. A Scheffé Test was performed on the data. The results indicate the difference observed between the code and non-code groups in the non-control condition are significant at the .05 level.

Figure 1 also shows shorter search times for the control condition over the non-control condition. The difference in search times was found to be highly significant, $p < .001$.

The mean search times for each density level across

FIGURE 1

Code by Control Interaction

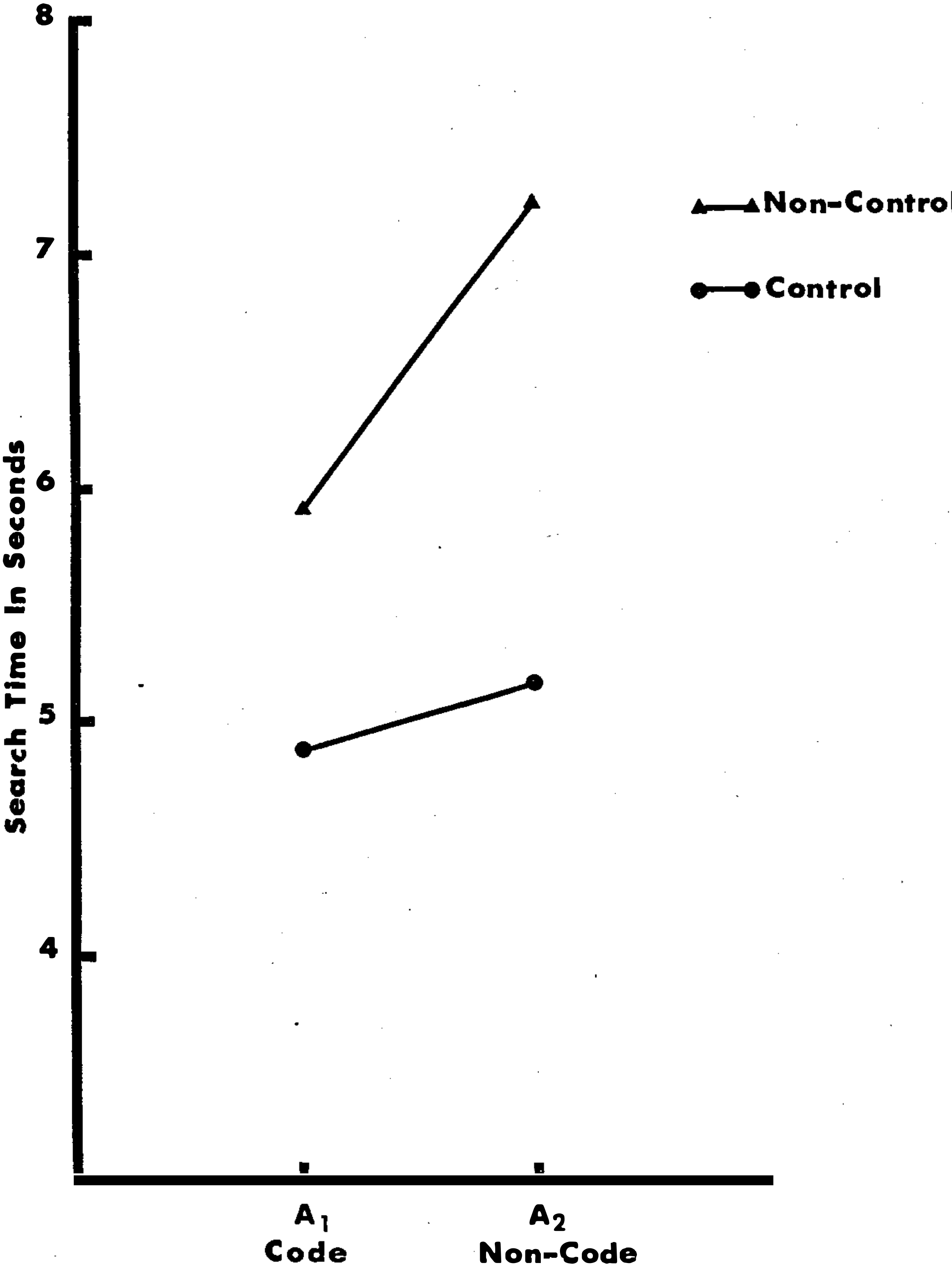


FIGURE 2

Search Times for Six Density Levels

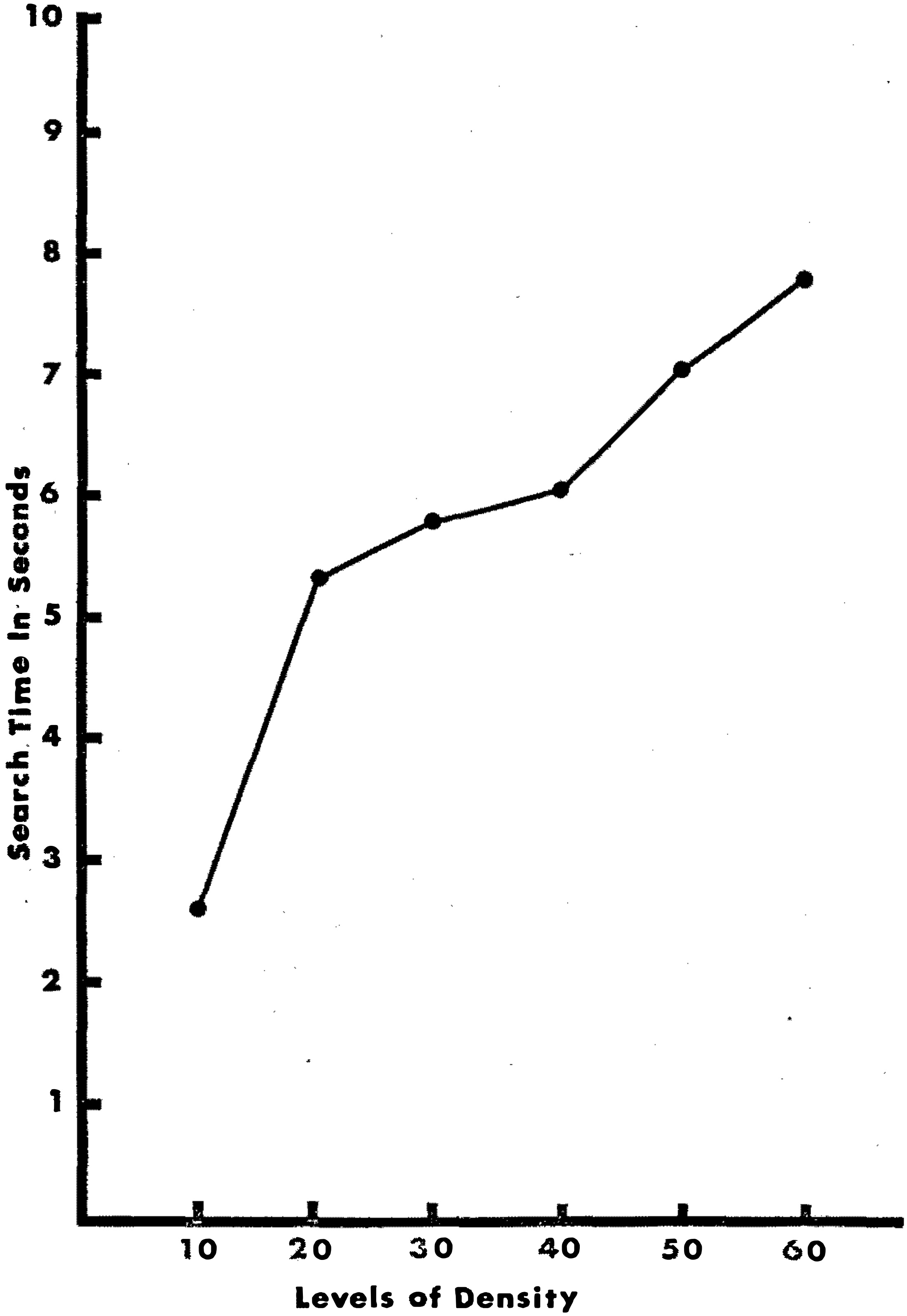
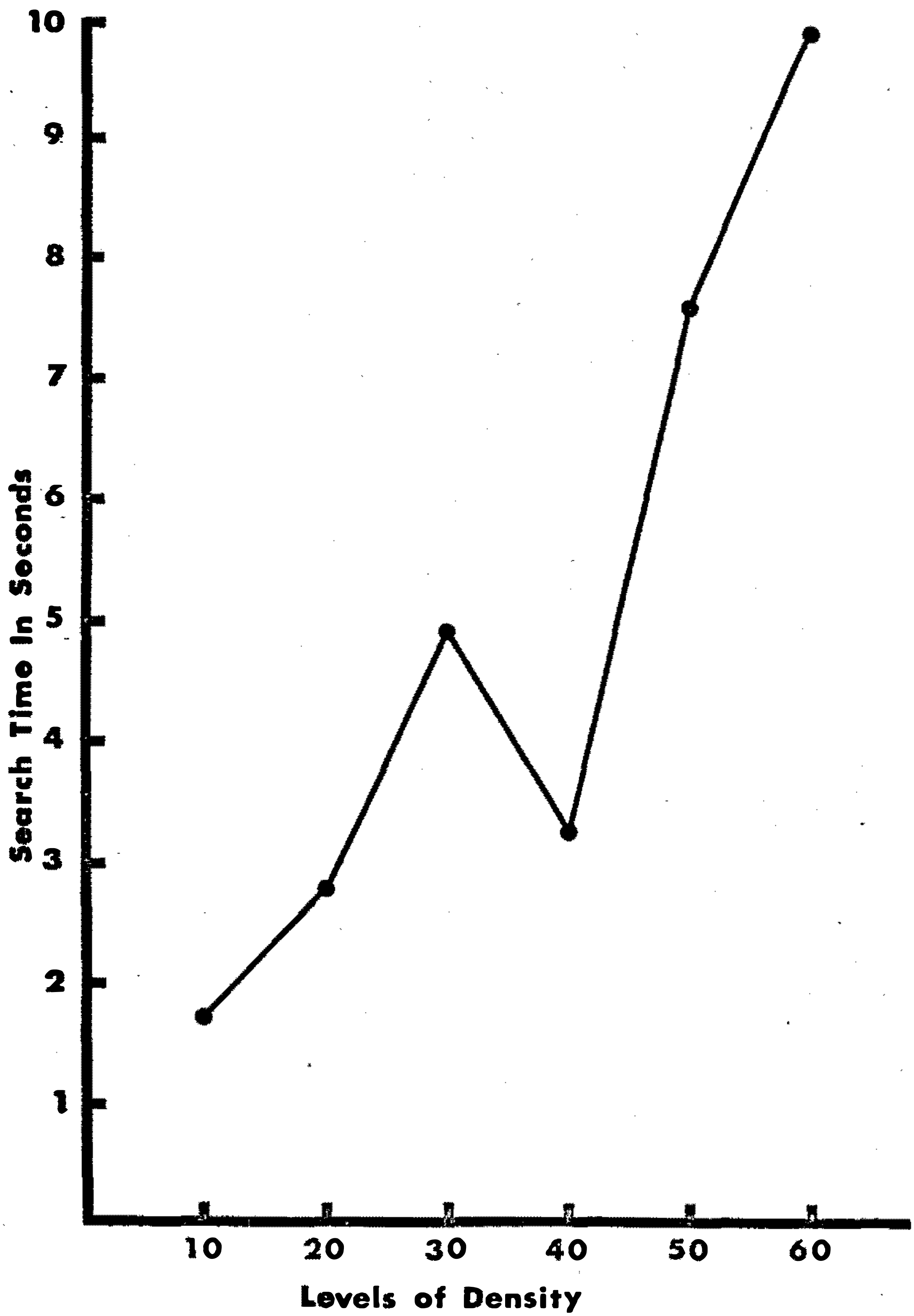


FIGURE 3

Control by Density Interaction



all other conditions are plotted in Figure 2. The search times are observed to increase as the density of the potential target numbers increases.

The mean times for the control by density interaction are plotted in Figure 3. Again the search times are observed to increase as density increases. The non-control by density interaction plotted in Figure 4 is broken into its code and non-code components. The code and non-code plots appear to be essentially parallel. The general appearance of the plots could best be described as an inverted U.

In order to determine search rates, the amount of information processed must be divided by the time needed to process the information. With sixty possible numbers the information contained in each number was $\log_2 60$ bits. Therefore, for the control condition at the density level of ten, ten numbers were displayed each of which could be one of sixty possible numbers making the total amount of information present $10 \log_2 60$ bits. Similarly, the total information present on any of the other displays in the control condition was calculated by the formula $n \log_2 60$ where n is determined by how many numbers are present on the display.

Figure 5 is a plot of the processing rates for the control condition. The total information present in a display for each density level was divided by its respective search time to obtain these rates. Essentially the plot

FIGURE 4

Code by Non-Control by Density and Non-Code by Non-Control by Density

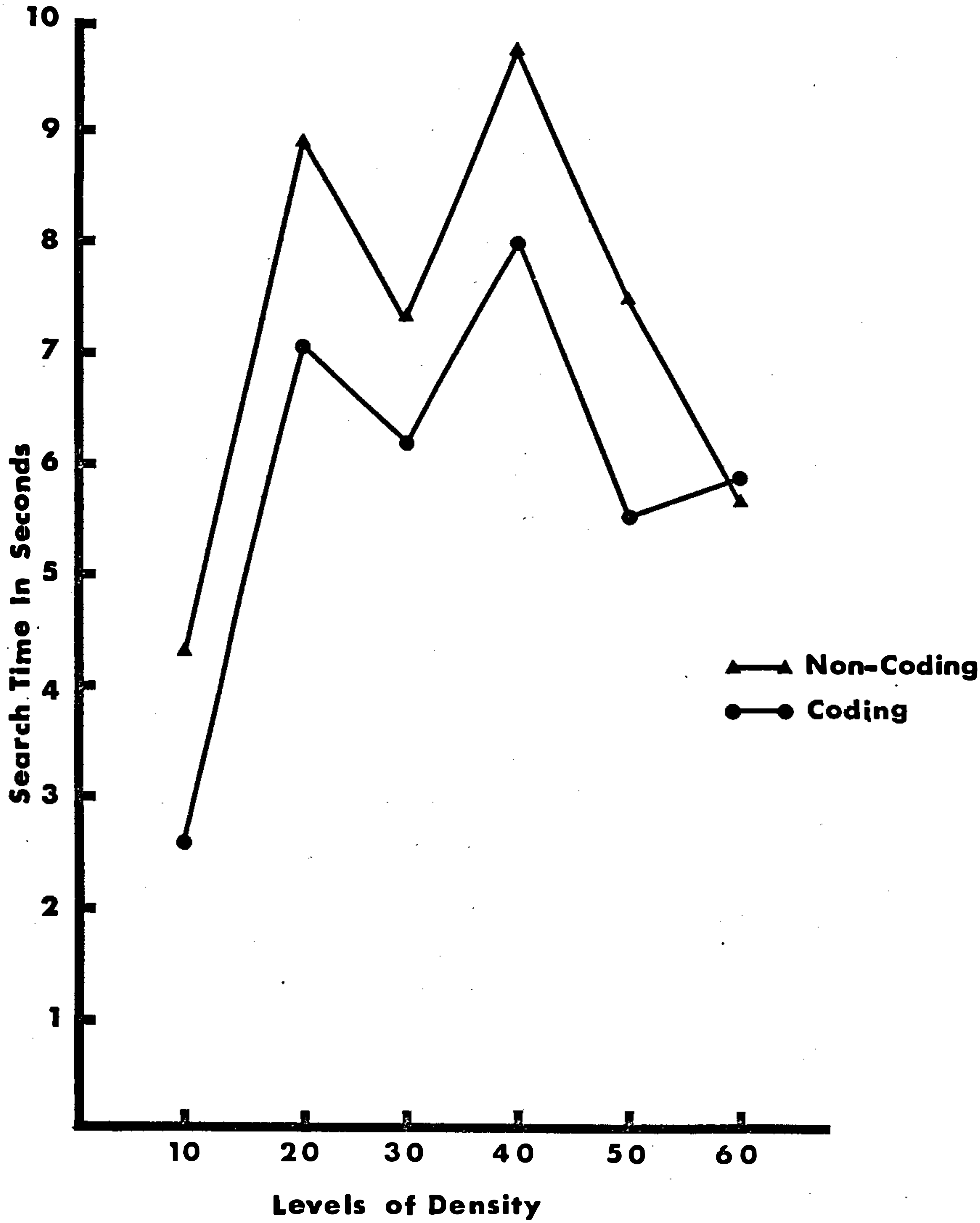
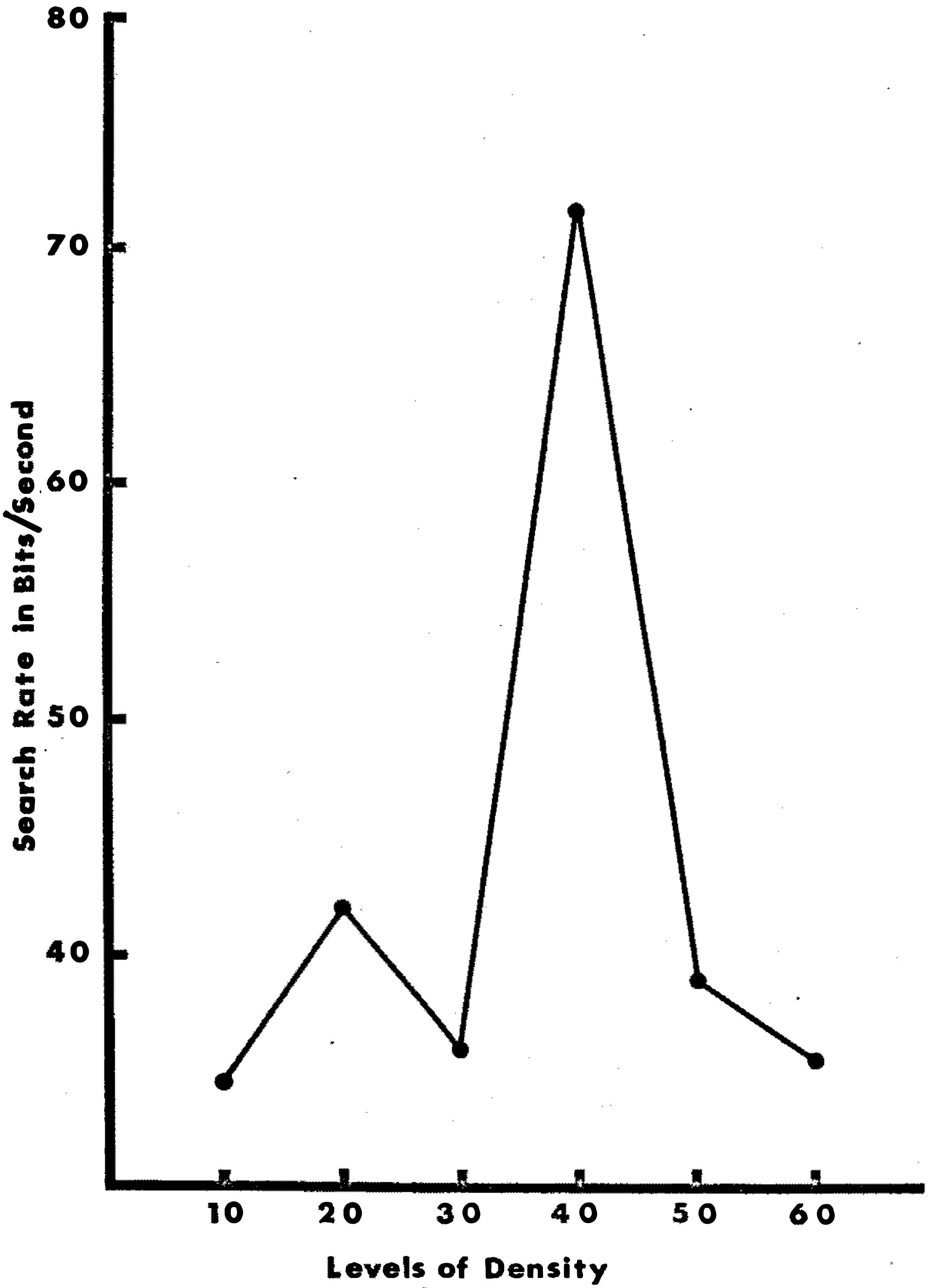


FIGURE 5

Processing Rates for Control by Density Interaction



in Figure 5 is linear with the exception of the density level of 40. The mean search rate excluding the density level of 40 was 37.6 bits/second.

The information totals for the non-control coding and non-control non-coding groups cannot be calculated, since the search strategy used by the subject prevents determining how many numbers were actually processed. This problem will be discussed later.

Discussion

The results indicating the significant difference between the coding and non-coding groups in the non-control conditions support the hypothesis concerning redundant information. The effect of a redundant code does indeed appear to decrease the time subjects need to locate a target in a visual search task. Green and Anderson (1956) found this to be true using color as the redundant code, and the present study extends this finding to geometric forms. Therefore, the effect of redundant coding has been demonstrated twice using different methods of supplying redundant information.

The large difference between the two control conditions illustrates the effect of irrelevant information on search times in a visual search task. The subjects in the control condition had only that information which was relevant to their task, hence, less information to process in locating the target. The subjects in the non-control condition had to process the same information processed by the control condition as well as information which was irrelevant to their task. The data gives support to the supposition that irrelevant information increases search times in visual search tasks.

The data also illustrates what happens when the amount of uncertainty is increased in a search task. The subjects in this study required more search time as the pool of numbers from which the target may be found was increased. The increase in the number pool increases the number of alternative choices which increases uncertainty and therefore, increases the amount of information to be processed. Hence, an increase in information to be processed required more search time.

While the data from the control group shows the nearly linear increase in time as density increases, the non-control condition fails to do so. The subjects in the non-control by non-coding condition appear to have performed the search in a manner similar to that of the non-set group in the Green and Anderson (1956) study. The coding group in the non-control condition also seemed to have used the same approach in locating the target as both data plots are essentially parallel. Since the actual search strategy was not investigated by this study no means is immediately available to determine why both groups have the same curve on their data plots.

Meudell and Whiston (1970) in their analysis of the Green and Anderson (1956) study felt the subjects employed a redundant search strategy rather than a line by line search, since a line by line search would have produced a fairly constant search time. Such redundant strategies made the determining of how many numbers were actually scanned impossible.

Because the control condition was the only condition in which it was possible to determine how many numbers were really scanned, only that condition received analysis concerning information processing rate. The result of that analysis indicates an almost constant processing rate for each of the density levels as postulated. The only exception occurs at the density level of 40. This is the result of an exceptionally low search rate at this density level. At the present no explanation for such an occurance is available.

The results of this study suggest several areas of possible further study. Since coding was found to reduce search times on a visual search task, an investigation concerning the effects of a multiple redundant code would be a natural followup study. With the data of this study not lending itself to the investigation of processing rates further research should be done in this area. Specifically studies to determine a possible absolute rate of information processing regardless of search strategies or the presence of irrelevant information should also be performed. A third area of research would involve determining what search strategies subjects tend to develop when given no clues or help of any kind to suggest a strategy. This follows from the results obtained for the non-control condition in this study.

The results of this study indicate that the search times required by subjects in a visual search task will be reduced when a redundant code is used to identify the target. If a subject must process a larger amount of information in a visual search his time will also increase. Elimination of irrelevant information will also reduce the amount of search time needed. Some evidence was obtained to support the hypothesis of a constant information processing rate in visual search tasks.

References

Alluisi, E. A. On the use of information measures of form perception. *Perceptual and Motor Skills*, 1960, 11, 195-205.

Archer, E. J. Identification of visual patterns as a function of information load. *Journal of Experimental Psychology*, 1964, 48, 313-317.

Archer, E. J., Bourne, L. E., Jr., & Brown, F. G. Concept identification as a function of irrelevant information and instructions. *Journal of Experimental Psychology*, 1955, 49, 153-164.

Attneave, F. *Application of information theory to psychology*. New York: Holt, Rinehart, and Winston, 1959.

Eriksen, C. W. Location of objects in a visual display as a function of the number of dimensions on which the objects differ. *Journal of Experimental Psychology*, 1952, 44, 56-60.

Eriksen, C. W. Object location in a complex perceptual field. *Journal of Experimental Psychology*, 1953, 45, 126-132.

Garner, W. R. *Uncertainty and structure as psychological concepts*. New York: Wiley, 1962.

Green, B. F., & Anderson, L. K. Color coding in a visual search task. *Journal of Experimental Psychology*, 1956, 51, 19-24.

Gregg, L. W. The effect of stimulus complexity on discriminative responses. _Journal of Experimental Psychology_, 1954, 48, 289-297.

Hyman, R. Stimulus information as a determinant of reaction time. _Journal of Experimental Psychology_, 1953, 45, 188-196.

Miller, G. A. What is information measurement? _American Psychologist_, 1953, 8, 3-11.

Miller, G. A., & Frick, F. C. Statistical behavioristics and sequences of responses. _Psychological Review_, 1949, 56, 311-324.

Neisser, U. Decision-time without reaction-time: Experiments in visual scanning. _American Journal of Psychology_, 1963, 76, 376-385.

Neisser, U., Novick, R., & Lazar, R. Searching for ten targets simultaneously. _Perceptual and Motor Skills_, 1963, 17, 955-961.

Olshavsky, R. W., & Gregg, L. W. Information processing rates and task complexity. _Journal of Experimental Psychology_, 1970, 83, 131-135.

Oostlander, A. M., & de Swart, H. Search-discrimination time and the applicability of information theory. _Journal of Experimental Psychology_, 1966, 72, 423-428.

Rappaport, M. The role of redundancy in the discrimination of visual forms. _Journal of Experimental Psychology_, 1957, 53, 3-10.

Shannon, C. E., & Weaver, W. The mathematical theory of communication. Urbana: University of Illinois Press, 1949.

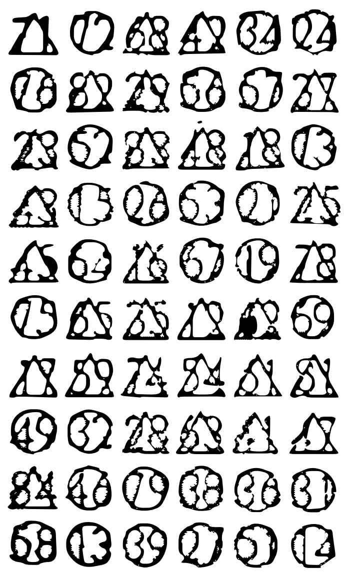
Smith, S. L. Color coding and visual search. Journal of Experimental Psychology, 1962, 64, 434-440.

Solley, C. M., & Snyder, F. W. Information processing and problem solving. Journal of Experimental Psychology, 1958, 55, 384-387.

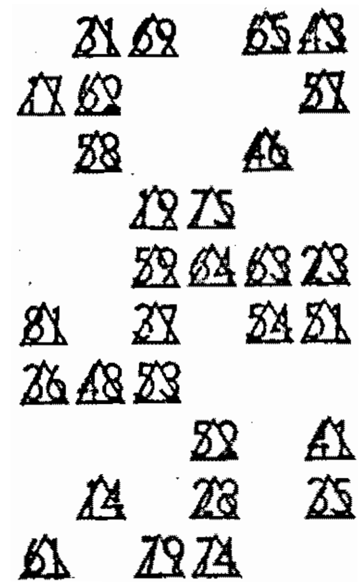
Thomas, A., & Solley, C. M. Search-discrimination time for missing stimulus information. Journal of Experimental Psychology, 1963, 65, 501-506.

Appendix A

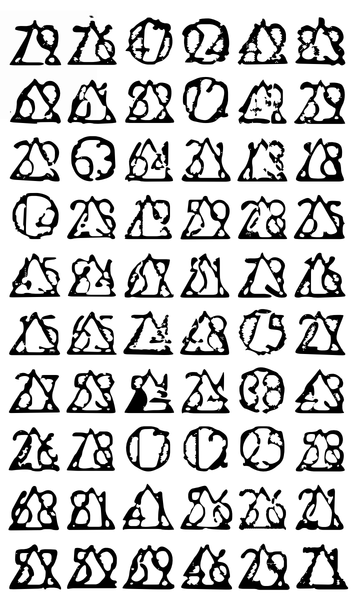
Examples of Stimulus Displays



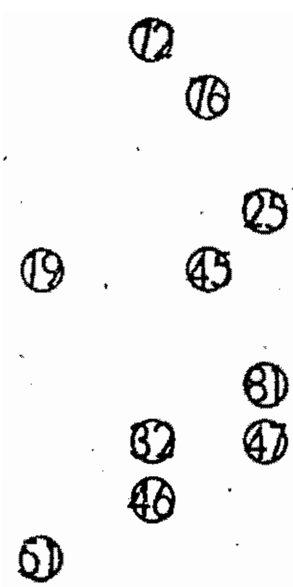
Target Code- Triangle
Density Level- 30
Non-Control



Target Code- Triangle
Density Level- 30
Control



Target Code- Circle
Density Level- 10
Non-Control



Target Code- Circle
Density level- 10
Control

Appendix B

The Instructions Read to the Subject

In this experiment a matrix of two digit numbers will be projected onto the screen. You are to locate as quickly as you can the particular two digit number I give you. Before each new slide I will give you a new two digit number (and the form, triangle or circle, behind it).* You are to repeat the number (and form)* back to me. Some of the slides will show complete matrices while others will have empty places. In all cases you are to locate the assigned two digit number as quickly as you can. When you locate the number press the switch in your hand and say "now." If the target number is not there say so and press the switch. After you have done this indicate the location of the assigned target number.

Remember to locate the number as quickly as you can. Then press the switch and say "now" when you have found it. Do you have any questions?

We will now do some practice trials. Should you have any questions during the practice trials be sure to ask them. (When depressing the switch be sure to release it immediately.)

-Administration of Practice Trials-

Do you have any questions? We will now begin the first trial. Remember to locate the assigned number as quickly as possible, press the switch, and say "now" when you have found it.

*Those instructions within parenthese are for the code group only and are not for the non-code group.

Appendix C

Analysis of Variance for Collected Data

Source	Deg. of Freedom	Sum of Squares	Mean Square	F	
Between Groups	39	2628.1			
Code/Non-Code(A)	1	166.4	166.4	2.6	NS
Subject within groups	38	2461.7	64.7		
Within Groups	920	18124.4			
Triangle/Circle(B)	1	0.9	0.9	0.03	NS
A X B	1	52.7	52.7	1.9	NS
B X S within group	38	1067.0	28.1		
Control/Non-control(C)	1	568.4	568.4	76.5	$p < .001$
A X C	1	62.7	62.7	8.4	$p < .01$
C X S within group	38	282.3	7.4		
Density levels(D)	5	2655.6	531.1	36.4	$p < .001$
A X D	5	66.0	13.2	0.9	NS
D X S within group	190	2773.5	14.6		
B X C	1	21.4	21.4	3.3	NS
A X B X C	1	1.3	1.3	0.2	NS
B X C X S within group	38	249.2	6.6		
B X D	5	271.7	54.3	3.5	$p < .025$
A X B X D	5	67.7	13.5	0.9	NS
B X D X S within group	190	2961.3	15.6		
C X D	5	2772.2	554.4	51.4	$p < .001$
A X C X D	5	19.2	3.8	0.4	NS
C X D X S within group	190	2048.8	10.8		
B X C X D	5	422.9	84.6	9.6	$p < .001$
A X B X C X D	5	78.7	15.7	1.8	NS
B X C X D X S within grp.	190	1680.9	8.8		

Appendix D

Table of Cell Means Used to Make Graphs

	Control	Non-Control
Code (sec.)	4.9	5.9
Non-Code (sec.)	5.2	7.2

Mean Search Times in Seconds

	Density levels					
	10	20	30	40	50	60
Search Times	2.6	5.4	5.8	6.1	7.1	7.9
Control X Density	1.7	2.8	4.9	3.3	7.6	9.9
Code X Non-Control X Density	2.6	7.1	6.2	8.0	5.5	5.9
Non-Code X Non-Control X Density	4.3	8.9	7.3	9.7	7.5	5.7
Control X Density (in Bits/Second)	34.8	42.2	36.2	71.2	38.9	35.8